JOVIAN DECAMETRIC ECLIPSES BY THE GALILEAN SATELLITES

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Abstract

It is shown that the satellites Callisto and Ganymede can eclipse the sources of the Jovian decameter radiation (DAM). These events are a new promising instrument to explore the Jovian system with unprecedented possibilities (localization and fine structure of the DAM sources with 1km-resolution; detection of the Callisto and Ganymede ionospheres). The details and recommendations to observe such events are presented.

1 Introduction

The precise positions and fine structure of the Jovian decameter radio emission sources (DAM) are unknown. Thus it is suggested that the DAM is generated in the Io flux tube (IFT) or in the magnetic field lines crossing the Io plasma torus at the frequency of: $f = (1 + \delta)f_c$, where f_c is the local cyclotron frequency of electrons and δ the model parameter. There are essential discrepancies between various models: $0 < \delta \ll 1$ [Arkhipov, 1989; Arkhipov, 1991; Leblanc et al., 1994; Menietti et al., 1984], $\delta \sim 0.1$ [Green, 1984; Hashimoto and Goldstein, 1983], and $\delta \sim 1$ [Boev and Luk'yanov, 1991b]. Accordingly, the model positions of the DAM source differ up to ∼10000km at identical f. However even for assumed δ, the position uncertainty is about 10000km because of the possible errors in the models of the planetary magnetic field (e.g.: the contribution of unknown higher multipoles near the Jupiter [Warwick and Evans, 1984]; magnetic field of electrical currents in the IFT, and the IFT bending [Ryabov, 1994]) or due to the unknown long delay of DAM excitation by Io [Leblanc et al., 1994]. The DAM sources are still unresolved by space probes and ground-based radio interferometers [Carr et al., 1983], but their location, dimension and fine structure, obviously, will be very important for the DAM theory. These problems could be solved by the classical occultation method. Unfortunately, such an approach was not used for the Jovian radio emission so far. The Moon occultations are too rare for the sporadic DAM. For example, the author's attempt to record the lunar occultation of Jupiter on May 26, 1983, failed because of radio interference. Nevertheless the DAM eclipses by the Galilean satellites occur more frequently. However, this possibility was not explored before.

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2 Satellite Selection

There are three criteria to select the satellites for the occultation method:
(**a**) for the occultation of the possible DAM regions, the satellite orbit radius must be: $a \geq R_J/sinD_m$ (where R_J=66740km is the polar radius of Jupiter [Arkhipov, 1989]; D_m=3.3^o is the maximum Joviocentric declination of the Earth);
(**b**) for the shadow darkness, the radius of the satellite must be larger than the first Fresnel's zone: $R > R_{min} = (a\lambda)^{0.5}$ (where: λ is the wavelength);
(**c**) for the definition of the diffraction pattern, the satellite must be sufficiently smooth (the ridge irregularities must be smaller than $H = a\lambda/2R$).
According to these criteria the most suitable satellite is Callisto. For about 64 percent of time it can occult the regions of the DAM generation within the whole frequency region every 16.75 days. Its radius (R=2400km [Morrison, 1982]) exceeds 10-18 times the lower limit of criterion (b) at 10MHz<f<30MHz. The icy mountains of Callisto are lower than 1km [Morrison, 1982] or they are less than (0.08-0.26)H in the same frequency range. At maximum Joviocentric Earth declination Ganymede can also occult the very northern end of IFT. It has a radius of R=2631km [Morrison, 1982] (15<(R/R_{min})<25 at 10MHz≤f≤30MHz) and smooth relief - the ridge irregularities are less than 0.7km or equivalently less than (0.11-0.34)H.

3 Phenomenology of Eclipses

The DAM occultation could be noticeable from the Earth as an elongated shadow with concentric edge pattern in the DAM dynamic spectrum within the frequency region from 39.5MHz to 3MHz (at $\delta \ll 1$ and GSFC O4 magnetic model). The radio shadow dimensions are (∼3MHz)∗(∼14min.) for Callisto and (∼8MHz)∗(∼10min.) for Ganymede. At a distance of 5AU the orbit radius a corresponds to $1.88 \cdot 10^6$km and $1.07 \cdot 10^6$km for Callisto and Ganymed, respectively, and for 10MHz≤f≤39.5MHz the diffraction on the satellites is nearly the same as the Fresnel diffraction on the flat disk [Azrilyant and Belkina, 1957]. The diffraction pattern on the shadow border is calculated by the Fresnel zone method (Figure 1). It follows from the calculations that the radio flux decreases (or increases) to 10dB during ≤27s for Callisto (f=20MHz) or ≤11s for Ganymede (f=35MHz). Hence, the diffraction pattern could be quite observable on the L-background of powerful A, B, C-sources. The border bright ring (the first diffraction maximum) could be a characteristic marker for the shadow identification in the DAM dynamic spectra. The shadow borders can be defined with ∼10s-accuracy. Hence, the source could be located with ∼100km-error. This error could decrease dramatically if the central spot (named the Poisson spot) is observed. As the mountains are lower than the first Fresnel zone along the satellite limb (i.e., criterion (c) in the previous part), the Poisson spot must be detected as a bright detail right in the center of the shadow (Figure 2). Formally, the maximum flux of radio emission in the Poisson spot is about the DAM flux without the eclipse. However, its dimension is only d∼1000km near Earth (at the 1/2-level of the spot amplitude and the point source). Hence, the localization error of the DAM source could be $\sim ad/5AU = 4$km for Callisto at 20MHz, and 1km for Ganymede at 35MHz). Moreover, the Poisson spot is

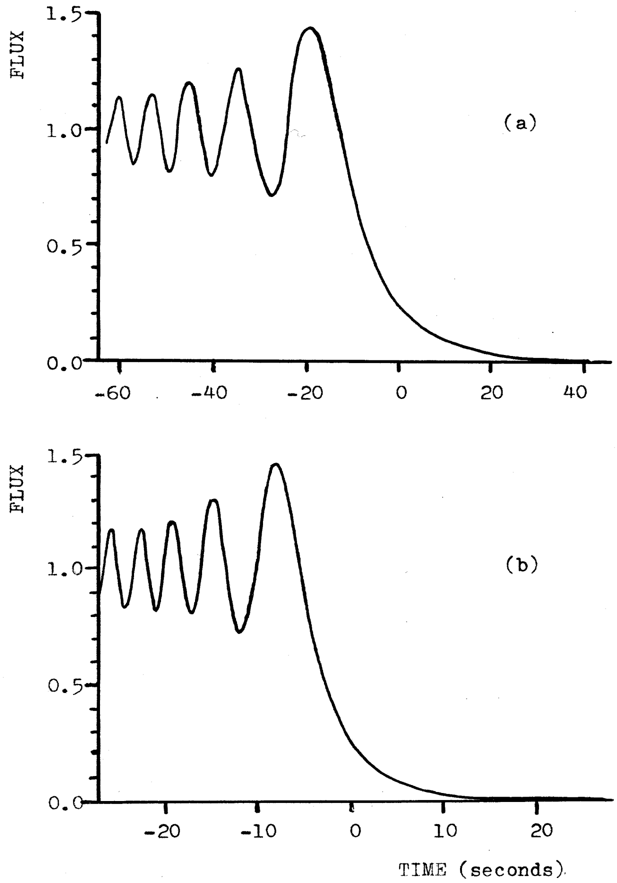

Figure 1: The theoretical DAM flux variations during the central disappearance of the point DAM source behind the edge of the ionosphereless Callisto (a) at f=20MHz and Ganymede (b) at f=35MHz. It is assumed that the flux without the eclipse effect is one unit. The zero time corresponds to the occultation moment.

the quasimonochromatic image of the DAM source with unprecedented ~1km-resolution. For the broadband L-background this image must be in the center of the shadow with more than 0.5s $\cdot$ 3kHz or 0.1s $\cdot$ 2kHz dimensions for Callisto and Ganymede, respectively. Therefore the Poisson spot could be detected with the equipment used for observations of S-bursts being somewhat intermediate between L- and S-emissions. The simultaneous Poisson spot observations from separated sites (at~1000km-distances along the meridian) are desirable for the two-dimensional mapping of the DAM source. As a matter of fact measuring the shadow diameter could reveal the refraction widening due to the ionosphere of the satellite.

4 Search for Eclipses

For the eclipse search it is reasonable to estimate the average frequency of such events: $\nu = (GM+KV)/P$, where G and K give the probability of the Joviocentric Earth's declination favorable for occultations of the northern or southern IFT branches, respectively; M and V are the probabilities of the satellite projection on the northern (RH-polarized) or

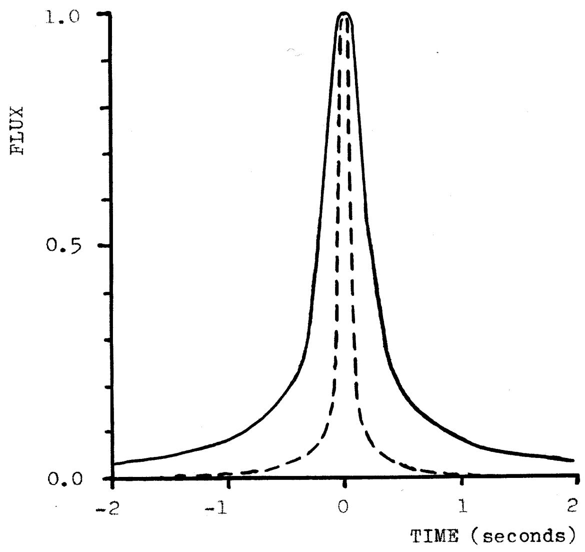

Figure 2: The Poisson spot profile for the point DAM source and ionosphereless Callisto (the solid line; f=20MHz) and Ganymede (the dashed line; f=35MHz). The flux unit is the DAM flux without eclipse. The zero time corresponds to the observer transit across the center of the satellite shadow.

southern (LH-polarized) L-emission, respectively, (the relative area of RH or LH polarized Io-sources on the CML-Φ_{Io} plate were assumed as these probabilities); P is the synodic orbital period of the satellite. Then for Callisto we obtain: G=0.33, K=0.31 (estimated by the Monte Carlo method), M=0.07, V=0.076 (for 20MHz [Carr et al., 1983]), ν=1.0yr^{-1}; and for Ganymede: G=0.12, K=0, M=0.03 (for f$\geq$30MHz [Genova and Aubier, 1985]), ν=0.2yr^{-1}. Thus, the search for DAM eclipses is quite real. Unfortunately, the archival search for eclipse-like events in the UTR-2 and Nançay DAM patrol data is unsuccessful so far because of radio interference and unsuitable time for observations. Therefore, new observations are desirable.

5 Conclusions

The Jovian DAM eclipses by Callisto and Ganymede are a new promising instrument for exploring the Jovian system because they could: (a) precisely localize the regions of DAM generation; (b) reveal the fine structure of the DAM sources up to 1km-resolution; (c) detect the Callisto or Ganymede ionospheres. Therefore, new observations and archival search are worth the effort.

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